Diapycnal Mixing in a Coastal Regime – AESOP

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LONG-TERM GOALS

To identify the major processes producing mixing in the upper ocean and to understand their dynamics sufficiently well to permit accurate parameterization of mixing for use in numerical models.

OBJECTIVES

These measurements during August 2006 were the first attempt we know of to survey a coastal domain with sufficient coverage to assess how mixing levels vary across the domain. Previous measurements have been concentrated in sub-regions, often revealing particular mixing processes, but insufficient to represent mixing throughout a regional model.

APPROACH

We ran lines of microstructure profiles 5-10 km long, balancing needs for rapid temporal sampling against spatial windows containing at least some structure. Staying with each line for 12.5 hours resolved changes produced by the M2 twice-daily tide, and some lines were rerun at different phases of the monthly tide. As we began to understand patterns of tidal currents and mixing, the original set of lines was modified to reveal pulsing of water in and out of the large canyon splitting the bay down its middle. Powerful Doppler sonars installed on R/V Revelle by Rob Pinkel at Scripps, provided excellent velocity records, supplemented by a 300 kHz ADCP we installed on the bottom the bay's southern half.

WORK COMPLETED

One paper, dealing with the most unexpected aspect of the measurements, is being reviewed for publication in the Journal of Physical Oceanography. Its contents are summarized below.

RESULTS

The first track run in the bay revealed remarkable vertical bands of intense turbulence, not observed previously by us except when probes were fouled or broken by organisms, such as jelly fish (Fig. 1). In these cases, however, the probes were not fouled, and there were matching signatures in the ship's ADCP and our acoustic backscatter system.

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14. ABSTRACT
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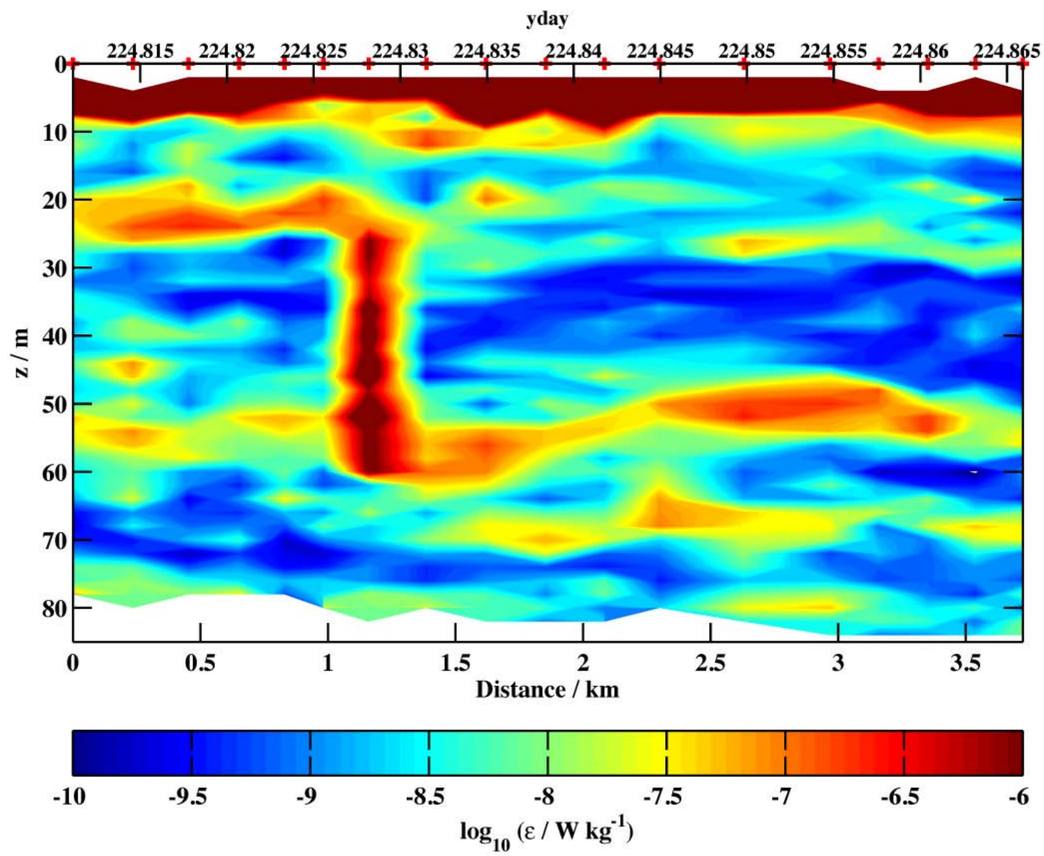

Fig. 1. Turbulent dissipation rate during one transit along a track in the southern half of the bay (Gregg and Horne, 2008). Time in digital year days is shown along the upper x axis, and distance from the west end of the track is plotted along the lower x axis. The image is colored by log10 of the turbulent dissipation rate. Normally, vertical bands of intense dissipation are produced by broken probes, but this probe was fine and remained in use for days.

Overlaying dissipation profiles on backscatter intensity demonstrates the profiler passing through a fish aggregation (Fig. 1). The species cannot be determined solely from acoustics, but anchovy are common in the bay at that season, and the backscatter was consistent with previous images from them season (F. Chavez, personal communication). Most likely, the fish were schooling, cruising with regular spacing and similar speeds, but, lacking net tows, we cannot be certain and use the broader term aggregation rather than school.

Varying between 10^{-6} and 10^{-5} W/kg, the dissipation rate in the aggregation was two to three decades larger than in background mixing patches. Similar rates were also found in most other aggregations, in striking agreement with predictions based on work expended during swimming based on ‘tail up’ analyses using standard drag expressions (Huntley and Zhou, 2004) and on bulk energetics (Dewar et al., 2006). Along this line, the handful of aggregations encountered were responsible for half of the net dissipation.

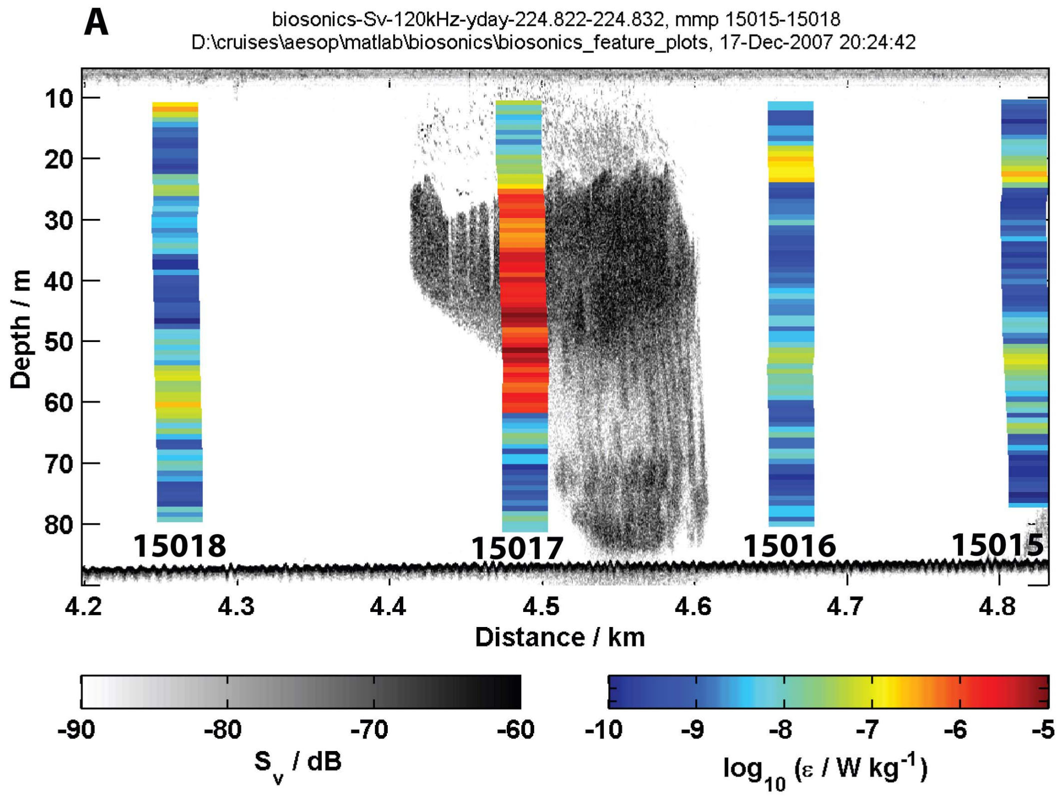

Fig. 2. Volume Backscattering Strength, S_v, in dB re 1 m^{-1}, at 120 kHz in grayscale overlaid with profiles of log10(ε) in color (Gregg and Horne, 2008). Each profile is tagged with its number in the sequence of drops taken with the Modular Microstructure Profiler (MMP). Profile 15017 penetrated a fish aggregation extending from the mixed layer base to the bottom. The aggregation was 200 m wide at the top and half that at the bottom.

Normally, intense turbulence satisfies conditions for universal turbulence including spectra with universal shapes and rms overturning scales matching the Ozmidov scale for buoyancy-limited turbulence. Neither of these conditions is met in the aggregations. Shear spectra are universal at highest wavenumbers, where viscosity smoothes fluctuations, but at lower wavenumbers observed spectra fall well below the universal shape. Variance-preserving forms peak near 8 cpm, corresponding to wavelengths of 12 cm, the average length of anchovy.

Turbulence in stratified fluids expands vertically by vortex pairing until the energy-containing scales of the vortices can no longer overturn the stratification. Known as the Ozmidov scale, this limit, $L_{oz} = (\varepsilon/N^2)^{1/3}$, is usually within 10-20% of average rms overturning scales. Within the aggregations, Loz was 1-2 meters, but overturns were 10 cm or less, as apparent in the typical temperature record plotted in Figure 3. Apparently, anchovy aggregations generate turbulence at scales within the dissipation range, close to the peak of the dissipation shear spectrum.

Consistent with this picture of anomalous turbulence within aggregations, estimated mixing efficiencies were much smaller than found elsewhere. Following now established practice, we estimated mixing efficiency by comparing simultaneous estimates of ε and χ, the rate of dissipation of

temperature fluctuations by thermal diffusion enhanced by turbulence. Much of the temperature gradient variance was too small to be measured by a thermistor falling at 0.7 m/s, but good and consistent estimates were obtained by fitting the Batchelor spectrum at lower wavenumbers. Most aggregation efficiencies were 0.001 – 0.01, compared to averages near 0.2 in background turbulence.

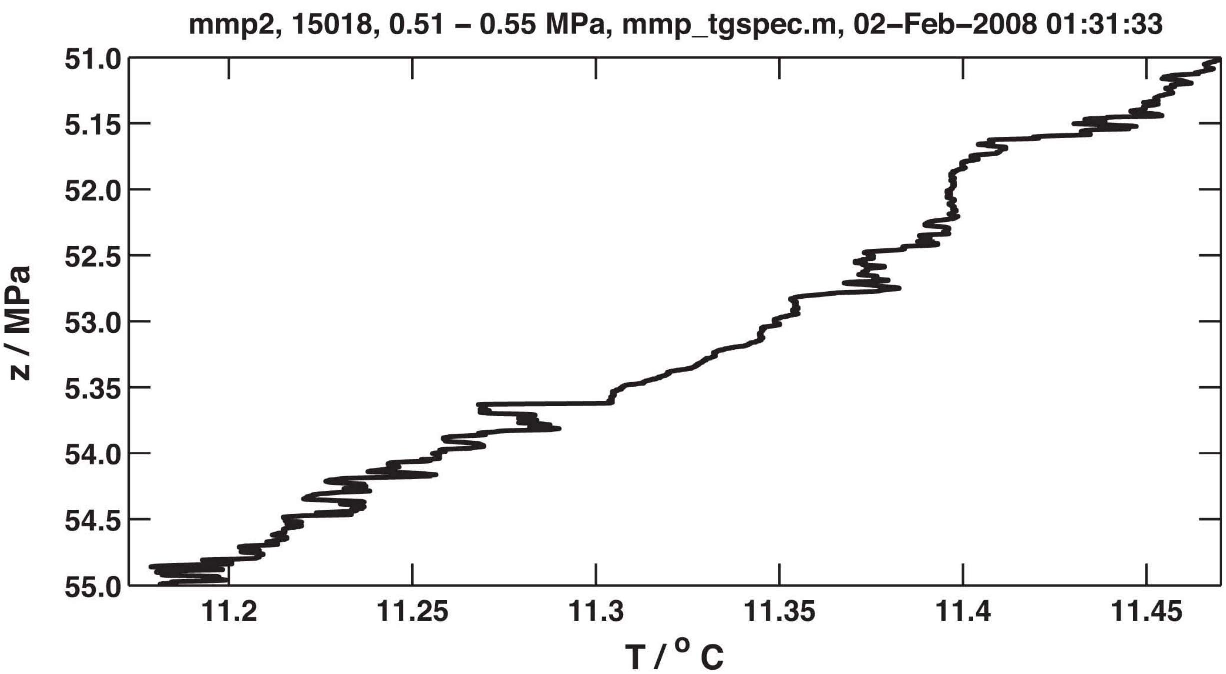

Fig. 3. High-resolution temperature, measured with an FP07 thermistor, through part of the aggregation shown in the previous figure (Gregg and Horne, 2008). Because the TS relation was approximately linear, temperature is a good surrogate for density, revealing rms overturns of about 10 cm compared to an Ozmidov scale greater than 1 meter.

In sum, aggregations in Monterey Bay indeed alter dissipation averages as hypothesized, but reduced mixing efficiency results in no significant change in diapycnal diffusivity.

IMPACT/APPLICATIONS

The first evidence that turbulence produced by fish is very inefficient, this report is likely to alter the ongoing debate about the global importance of biomixing and provide metrics for further observations of other fish species.

RELATED PROJECTS

To test the general applicability of these results, John Horne and I submitted a proposal to NSF to observe turbulence produced by larger fish species. Aside from the bioturbulence, magnitudes and patterns of mixing in Monterey Bay provide a direct comparison with observations from two other coasts where we worked recently, the Aegean and the Turkish Black Sea.

REFERENCES

Dewar, W, R. Bingham, r. Iverson, D. Nowacek, L.St. Laurent, and P. Wiebe (2006), *Does the marine biosphere mix the ocean?* **J. Mar. Res.,** 64, 541-561.

Gregg, M.C. and J.K. Horne, 2008, *Turbulence, acoustic backscatter and pelagic nekton in Monterey Bay*, **J. Phys. Oceanogr**., submitted.

Huntley, M. and M. Zhou, 2004: *Influence of animals on turbulence in the sea*, **Mar. Ecol. Prog. Ser**., 273, 65-79.